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14. ABSTRACT
This report results from a contract tasking University College London as follows: The range of frequency in the THz region would have a number of advantages for secure wireless communication. The stronger water absorption in that range of frequency compared to the standard wireless carriers induces shorter distances of transmission and render the signal to be enclosed within a building more easily. Furthermore it offers a wide unused bandwidth from 100 GHz to 1.5 THz for the system proposed. However the THz frequency range has long been difficult to exploit for practical applications because of the lack of cheap, compact, spectrally pure and power efficient sources. Semiconductor electronic sources above 300 GHz have only very small (few μW) output. Current continuous wave (CW) photonic THz sources, such as the quantum cascade laser (from 1.3 THz with up to 17 mW –CW- output power (at 2THz, 4K [2]), operation from 4K to 47K [1,2]) require liquid helium cooling and have minimum frequencies above the frequency range of interest (2THz) when not using a magnetic field, while pulsed sources require bulky and expensive femtosecond pulse Ti-Sapphire lasers [3]. Approaches based on heterodyning of optical sources with photo-conductive detectors have limited spectral purity (MHz linewidth), stability (10s of MHz) and power (few μW). In recent work, funded by EPSRC under the PRINCE project, we have explored photonic generation of THz signals using telecommunications-based technologies as a route to cheap, compact, highly efficient, room temperature sources. In particular we have developed waveguide hot-electron photodiodes with world record output powers at THz frequencies (148 μW at 457 GHz and 25 μW at 914 GHz) [5]. We have combined these with work on optical frequency synthesis to realise a highly efficient (< 1W total electrical power input), spectrally pure (< 1 Hz linewidth), stable (Hz) and frequency agile source The objective of the proposed project is to realise a proof of concept of a THz communication system by using this low power consumption source.

15. SUBJECT TERMS
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UCL DEPARTMENT OF ELECTRONIC &
ELECTRICAL ENGINEERING

SHORT RANGE 10 GB/S THZ COMMUNICATIONS PROOF OF CONCEPT

Award number
FA8655-07-1-3043

Interim Report
May 2008

Martyn Fice
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Alwyn Seeds

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1 SUMMARY

This document reports preliminary results on our work to construct a 10 Gb/s communications link operating at THz carrier frequencies. In particular it presents the first results of an experimental investigation into the use of an uni-travelling carrier (UTC) photodiode as an optoelectronic mixer. An optoelectronic mixer is one that performs frequency mixing between one optical signal and one electrical signal. The mixed product is a frequency converted electrical signal. The experiment was conducted at relatively low frequencies in the GHz band and the down-converted output signal was measured as a function of both injected optical power level and the UTC bias voltage. The results confirm the feasibility of employing the UTC photodiode as an optoelectronic mixer. This is considered to be an important step forward in that the optoelectronic mixer removes the difficulties of coupling a THz local oscillator signal into the point contact electrical mixers used in current THz receivers. Further investigation of the technique at THz frequencies is being pursued and will be reported in the final report.

2 INTRODUCTION

The THz frequency region potentially has a number of advantages for secure wireless communication. The stronger water absorption in this frequency range, compared to the standard wireless bands, limits transmission distance and allows the signal to be more easily confined, for instance within a building. Furthermore it offers a wide unused bandwidth- from 100 GHz to 1.5 THz for the system proposed.

For a THz communications system we require (1) a THz source that can conveniently be modulated at high speed (Gb/s), and (2) a high sensitivity THz detector with which the information can be demodulated.

Photonic generation of THz signals using telecommunications-based technologies provides a route to cheap, compact, highly efficient, room temperature, CW sources. Heterodyning of two CW optical signals, each phase locked to lines in an optical comb, is used to generate modulation at THz frequencies, with the optical signal converted to THz radiation using a very wide bandwidth waveguide hot-electron photodiode driving an antenna. The THz output can readily be modulated by modulating one of the CW optical signals before heterodyning. All of the major components could be integrated using InP technology to realise a compact, low power consumption THz transmitter.

Techniques generally used for THz detection and power measurement, for instance Golay cells, are not fast enough for high-speed data demodulation. Instead, it is necessary to down-convert the received THz signal to a much lower intermediate frequency (IF), where conventional electronics can be employed. This requires a suitable mixer to be employed, with the modulated THz signal received via a suitable antenna as one input and a THz local oscillator (LO) signal at a frequency offset by the required IF as the other. The use of this coherent detection approach also enables a large increase in sensitivity, which could enable THz frequency communication over reasonable distances, as it will help in overcoming water absorption in the air.

The mixer for frequency down-conversion requires a component that exhibits nonlinear characteristics. The UTC, because of its nonlinear current-voltage characteristic, is a candidate for such a mixer, in addition to being a high-speed photodiode. The modulated THz signal received by an antenna is fed to the diode electrical contacts, and a THz-modulated optical local oscillator, generated by a heterodyne method similar to that used in the transmitter source, is applied to the optical input, to form a convenient optoelectronic mixer in a single device.

The overall scheme proposed for the proof-of-concept THz communications system is thus as shown in Figure 1. On the left is the transmitter, based on heterodyne photonic THz generation. The optical frequency comb generator, phase locked slave lasers, and high-bandwidth UTC photodiode for THz generation have all been demonstrated previously, and integration of these components is being investigated in other projects. The main novel element on the transmitter side to be demonstrated is the modulation of the THz signal by optical modulation of the output of one of the slave lasers.

The modulated THz data signal propagates over a short wireless link between two antennas to the receiver, shown on the right of Figure 1. The received THz signal is mixed with a THz LO, shown schematically as being generated by detection of an offset optical heterodyne signal in a photodiode, to generate an IF carrying the data signal, which is then detected by standard RF techniques. In practice, an UTC photodiode will be used as an optoelectronic mixer, as described above. Demonstrating that the UTC can be operated as an optoelectronic mixer and characterising its performance in this mode are key objectives for this project.

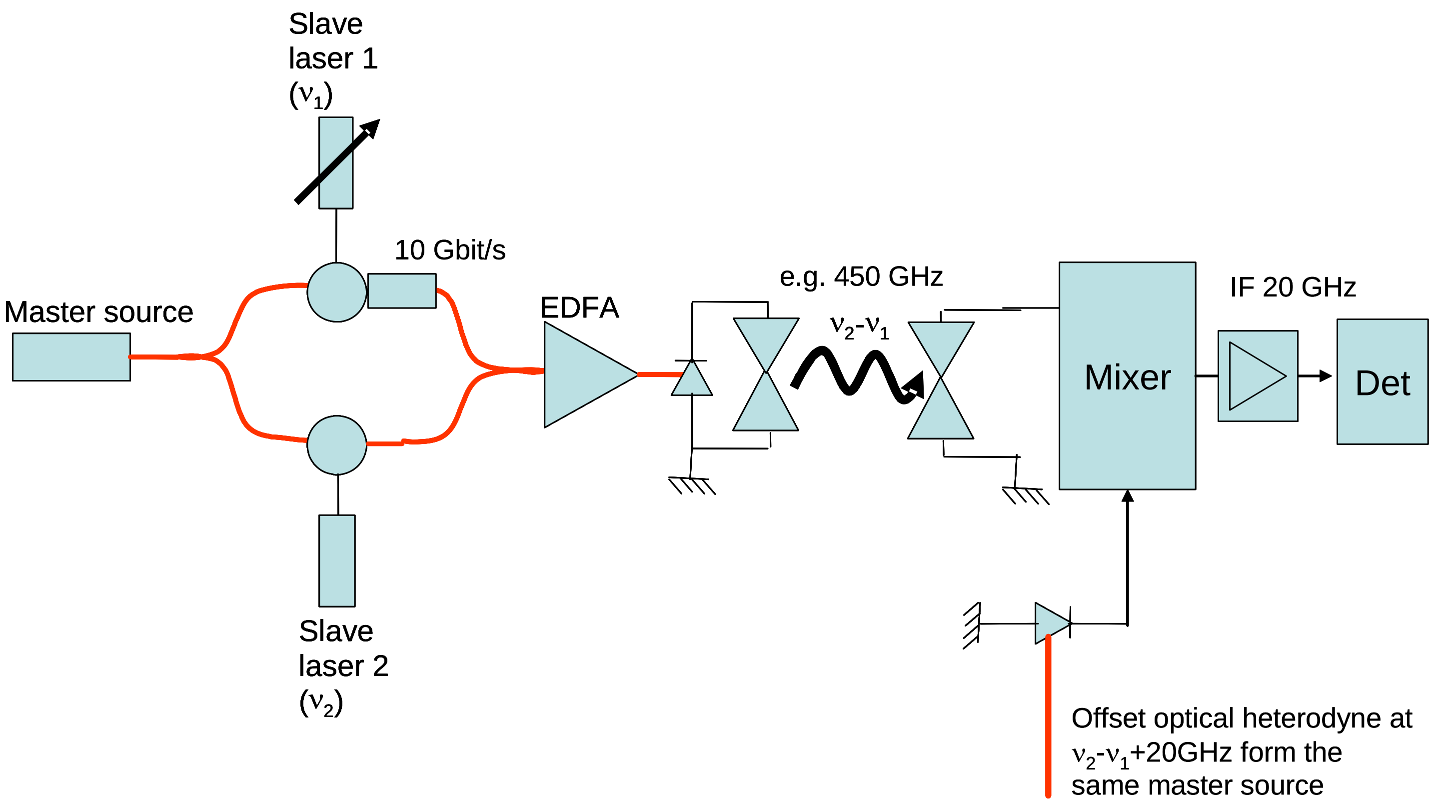

Figure 1: THz communications system

3 PROJECT OBJECTIVES AND PLAN

As outlined in the previous section, the key objectives for the project are to:

1. Demonstrate the UTC as an optoelectronic mixer, and characterise its performance up to THz frequencies. Although the UTC has demonstrated excellent performance to 1 THz as a photodiode, it has not previously been investigated as an optically pumped mixer. Areas to be investigated include its frequency response in mixer mode, and practical issues related to extracting the modulated IF.
2. Demonstrate data modulated THz source, with a target bit rate of 10 Gb/s.

3. Demonstrate coherent detection of the data modulated THz source using the UTC as an optoelectronic mixer.

An outline project plan showing the timing of the activities to be carried out to meet these objectives is shown in Figure 2.

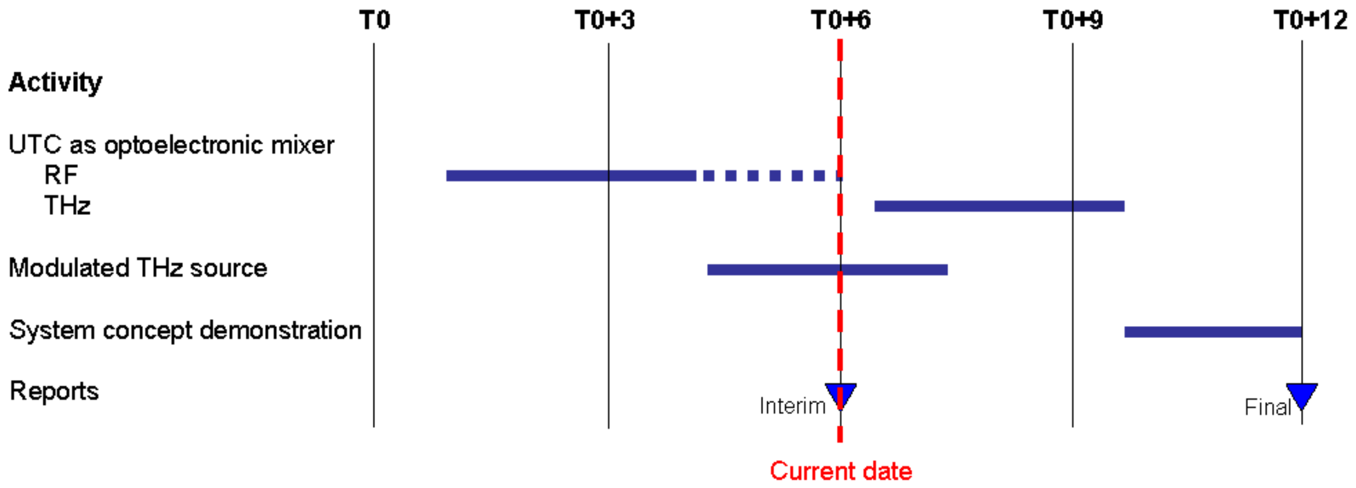

Figure 2: Outline project plan

In this reporting period, a preliminary study on the use of an UTC photodiode as an optoelectronic mixer has been carried out at GHz (rather than THz) frequencies. This has enabled the feasibility of using the UTC photodiode in this mode to be demonstrated in a much simpler experimental arrangement. An electrical radio frequency (RF) signal (representing the THz signal from the antenna) was mixed with an RF-modulated optical signal (representing the optical LO signal) in the UTC photodiode. The down-converted electrical IF signal (at frequency equal to the difference between the RF and the LO frequencies) was measured as a function of both the UTC photodiode bias voltage and the LO signal power level. Details of the experiment and the measured results are described in the following sections.

4 METHODS, ASSUMPTIONS, AND PROCEDURES

Figure 3 shows the experimental arrangement for performing optoelectronic mixing with an UTC photodiode. Electrical connection to the UTC photodiode was via a coplanar probe. A 10 GHz RF modulated optical signal was delivered to and focused onto the UTC photodiode using a lens-ended single-mode optical fibre. The 10.04 GHz electrical signal was provided by a microwave signal generator, which pumped the UTC photodiode electrically. This gave a down-converted IF signal at 40 MHz, which was measured with a spectrum analyser. In order to separate the applied 10 GHz optical LO signal and the 40 MHz down-converted IF signal, a microwave duplexer constructed using two filters (one separating the DC bias voltage and 40 MHz IF from the 10 GHz RF, and one separating the 40 MHz IF from the DC bias) was employed to channel these two signals.

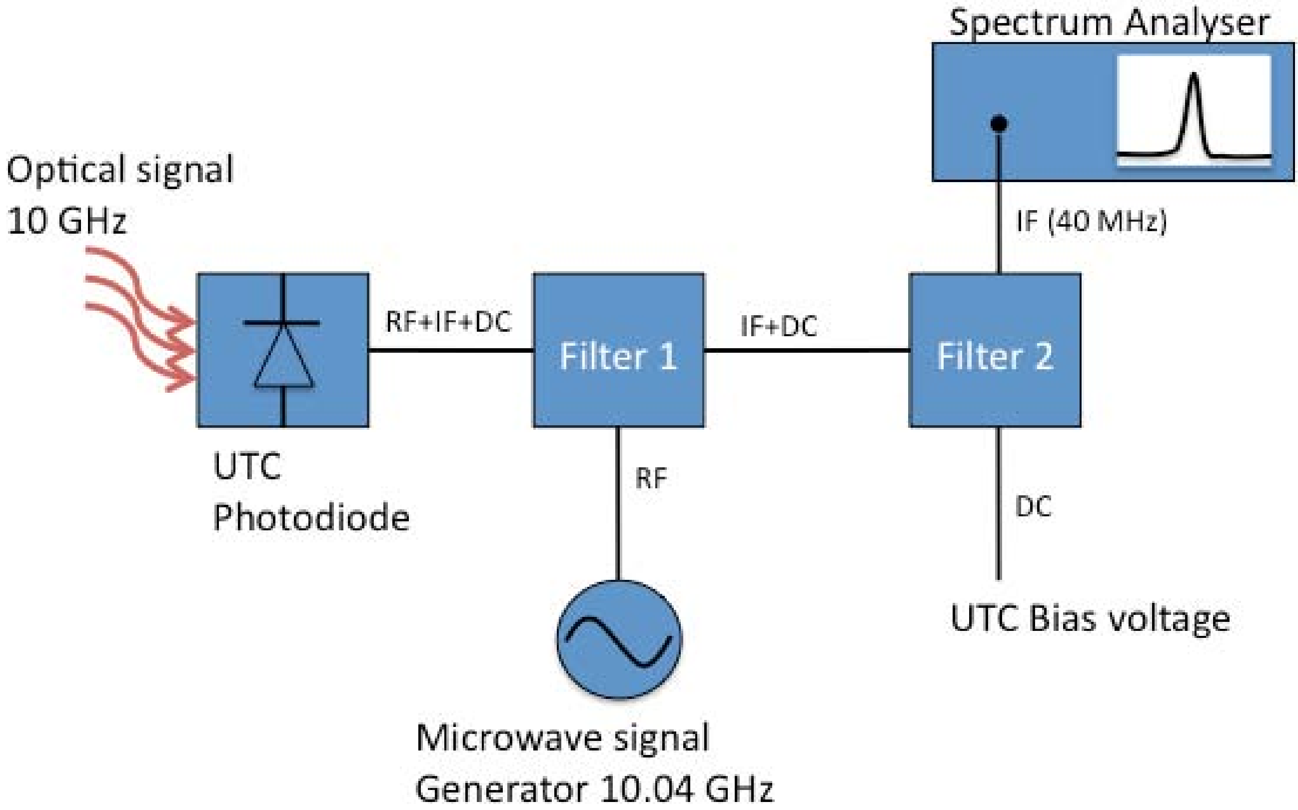

Figure 3: Experimental arrangement for performing optoelectronic mixing with a UTC photodiode

5 RESULTS AND DISCUSSION

Figure 3 shows the characteristics of the down-converted signal power at 40 MHz IF versus the 10 GHz optical LO power level at different reverse bias voltages. It can be seen that, in general, the measured IF power level increased with the LO power level which is common in any microwave mixer. Also as with other conventional diodes, the electrical current versus voltage characteristic is most nonlinear in the forward bias region. So with the LO signal superimposed on the reverse bias DC voltage, increasing the reverse bias DC voltage causes the UTC diode to spend more time in the linear reverse bias region and less time in the nonlinear (exponential) forward bias region. As a result, the down-converted IF power level decreased when the reverse bias voltage magnitude increased. However, for the optoelectronic mixer to function properly, the UTC diode should not be operated 100% in the forward bias region (i.e. when the total voltage swing due to the LO signal and the bias voltage always puts the diode in the forward bias region). This is because a large forward current will flow which could reach damage level for the diode. Also, the responsivity of the UTC diode decreases with decreasing reverse bias voltage magnitude.

In summary, the experimental results confirm the feasibility of using a UTC photodiode as an optoelectronic mixer and help in choosing an optimum operating bias voltage for the most efficient mixing process.

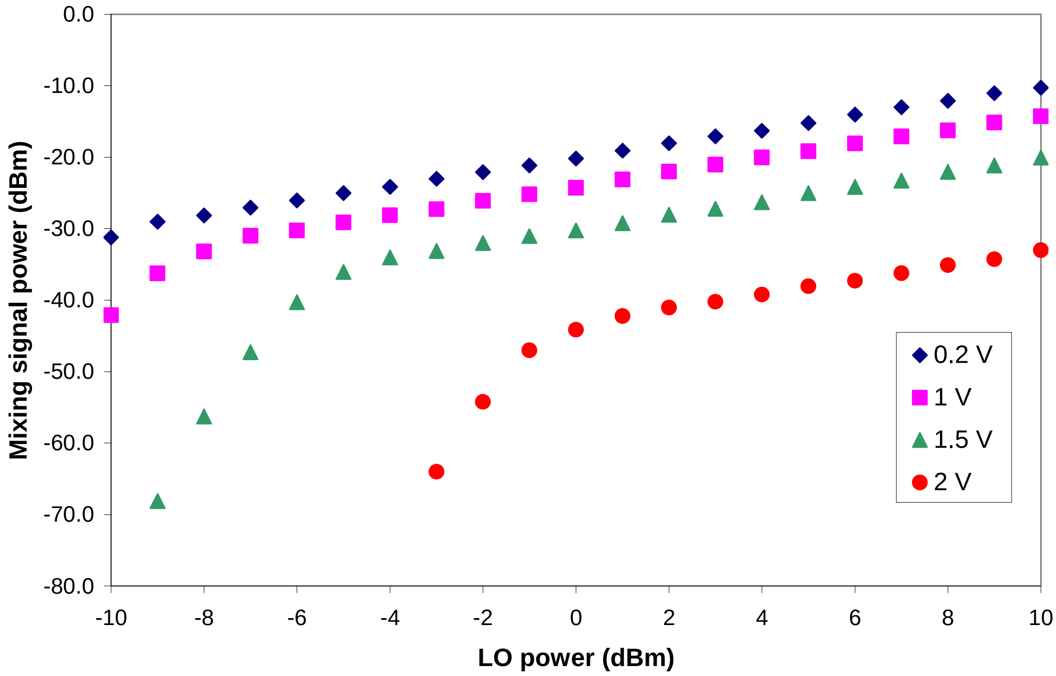

Figure 4: Characteristics of the down-converted signal power vs. LO power at different bias voltages.

6 FUTURE WORK

Work to extend the characterisation of the UTC optoelectronic mixer described in this report is underway to allow operation at higher frequencies. This aims first to increase the operation frequency to 65 GHz (instead of the 10 GHz reported here), and then towards 400 GHz. At these frequencies, the frequency response of the UTC photo-diode, which is dependent on bias voltage, is expected to have a greater impact on the overall response of the optoelectronic mixer. To move to higher frequencies, the filters required for combining and separating the RF (THz), IF and DC bias will have to be modified.

To test the UTC mixer beyond 65 GHz, heterodyne generation of the THz signal will be required, so in parallel with the above activity the THz data transmitter will be set up. This will also allow modulation and wireless transmission of millimetre wave signals to be demonstrated at frequencies up to 110 GHz, using standard test equipment for down conversion and spectral characterisation.

Finally, it is planned to demonstrate transmission of data over a wireless THz link using the UTC optoelectronic mixer for down-conversion, thus proving the concept of the THz communications system.

7 CONCLUSIONS

Preliminary experimental investigation has confirmed the feasibility of the UTC photodiode for use as an optoelectronic mixer. The UTC optoelectronic mixer was arranged to photodetect a 10 GHz RF modulated optical signal and mix it with a 10.04 GHz electrically applied signal. The down-converted signal at the 40 MHz IF was measured as a function of the LO signal level and the reverse bias voltage. The observed performance has been explained. Further investigation at THz frequencies is being pursued and will be reported in the final report.

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

AC: Alternating Current
DC: Direct Current
GHz: Giga Hertz
IF: Intermediate Frequency
LO: Local Oscillator
MHz: Mega Hertz
RF: Radio Frequency
THz: Tera Hertz
UTC: Uni-Travelling Carrier